

# NOAA's Operational Air Quality Forecasting: Progress and Challenges

Ivanka Stajner<sup>1</sup>, Jeff McQueen<sup>2</sup>, Pius Lee<sup>3</sup>,  
Ariel Stein<sup>3</sup>, Phil Dickerson<sup>4</sup>, Sikchya Upadhayay<sup>1,5</sup>

1 NOAA NWS/OSTI

2 NOAA NWS/NCEP

3 NOAA ARL

4 EPA

5 Syneren Technologies

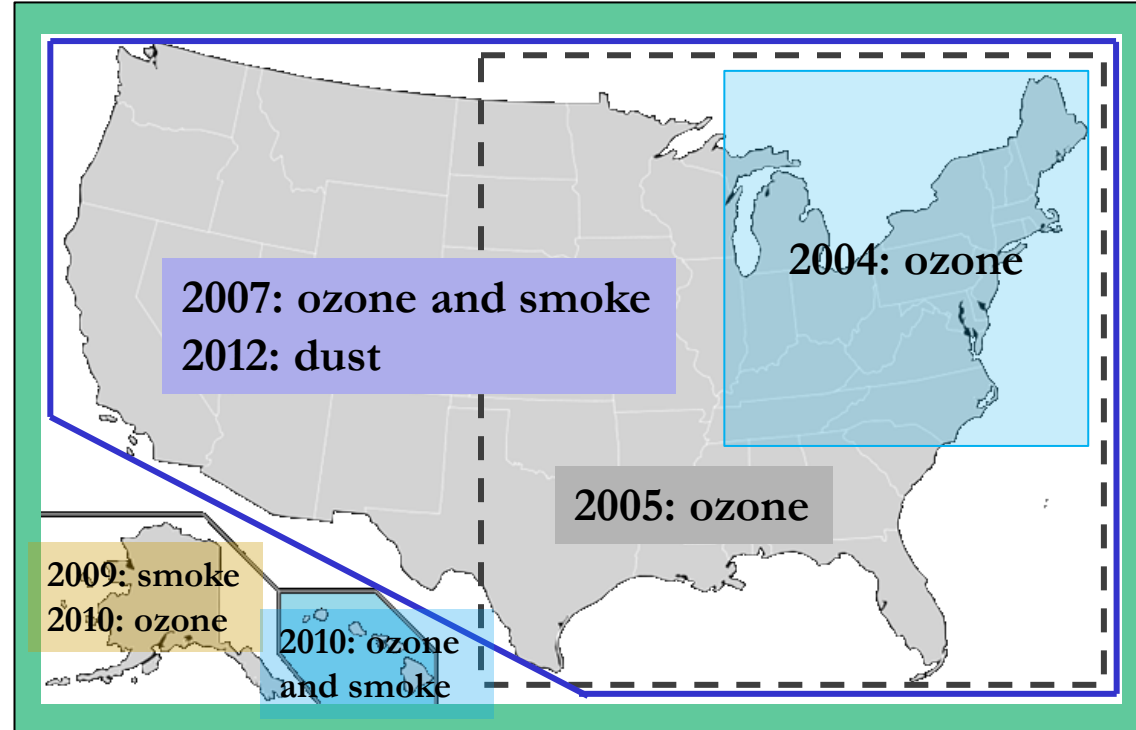
***with contributions from the entire NAQFC Implementation Team***

# National Air Quality Forecast Capability *status in 9/2015*

- Improving the basis for air quality alerts
- Providing air quality information for people at risk

## *Prediction Capabilities:*

- **Operations:**  
*Ozone nationwide*  
*Smoke nationwide*  
*Dust over CONUS*
- **Developmental testing:**  
*Components for particulate matter (PM) predictions*



# Ozone predictions

Operational predictions at <http://airquality.weather.gov>  
over expanding domains since 2004

## Model: Linked numerical prediction system

Operationally integrated on NCEP's supercomputer

- NOAA/EPA Community Multiscale Air Quality (CMAQ) model
- NOAA/NCEP North American Mesoscale (NAM) numerical weather prediction

Observational Input:

- NWS compilation weather observations
- EPA emissions inventory

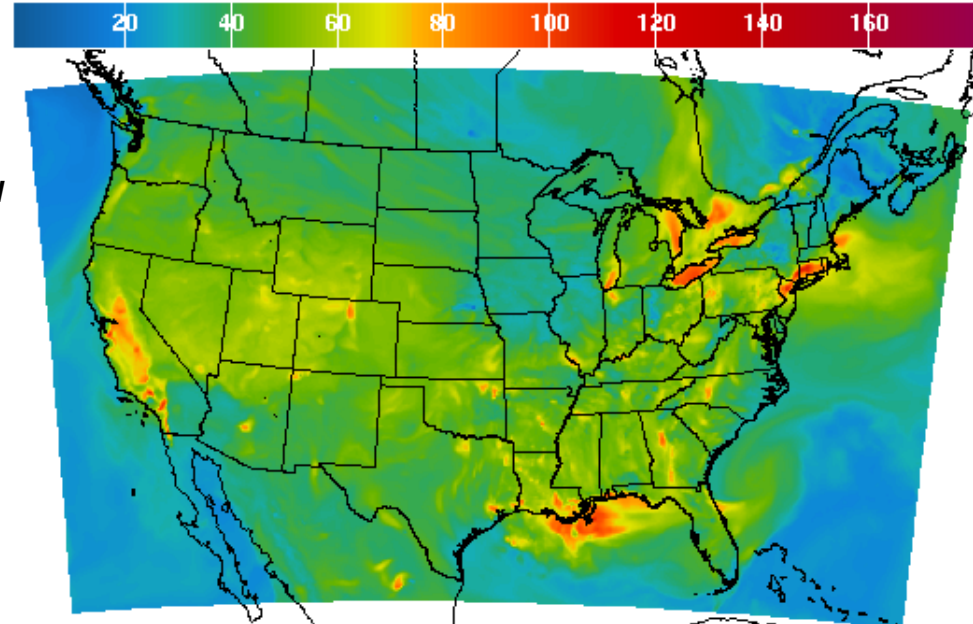
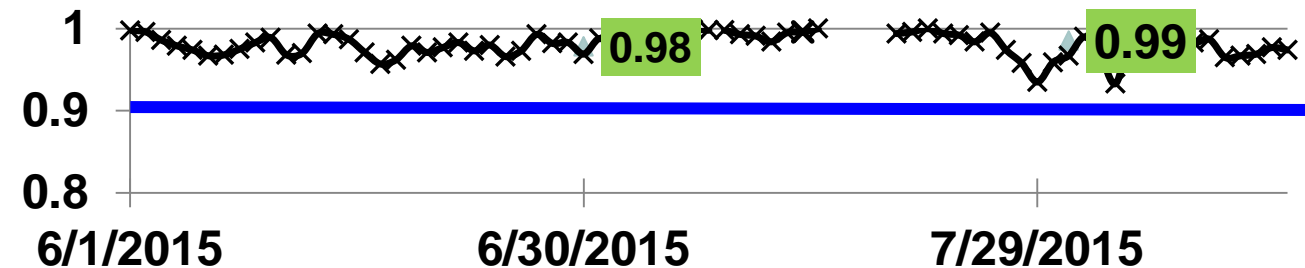
## Gridded forecast guidance products

- On NWS servers: [airquality.weather.gov](http://airquality.weather.gov) and ftp-servers (12km resolution, hourly for 48 hours)
- On EPA servers
- Updated 2x daily

Verification basis, near-real time: Ground-level  
AIRNow observations of surface ozone

## Customer outreach/feedback

- State & Local AQ forecasters coordinated with EPA
- Public and Private Sector AQ constituents



1Hr Avg Ozone Concentration(PPB) Ending Wed Jul 29 2015 7PM EDT  
(Wed Jul 29 2015 23Z)



National Digital Guidance Database  
12z model run Graphic created-Jul 29 12:23PM EDT

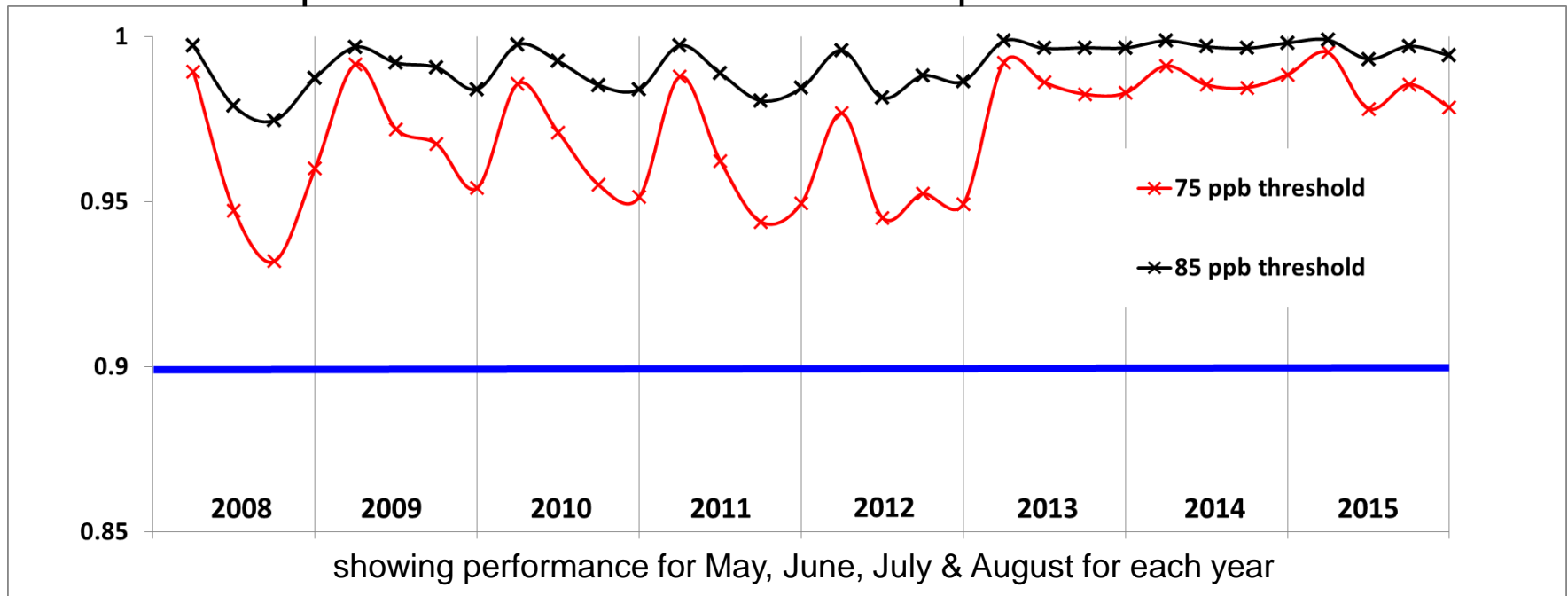


Operational  
CONUS, wrt 75 ppb Threshold

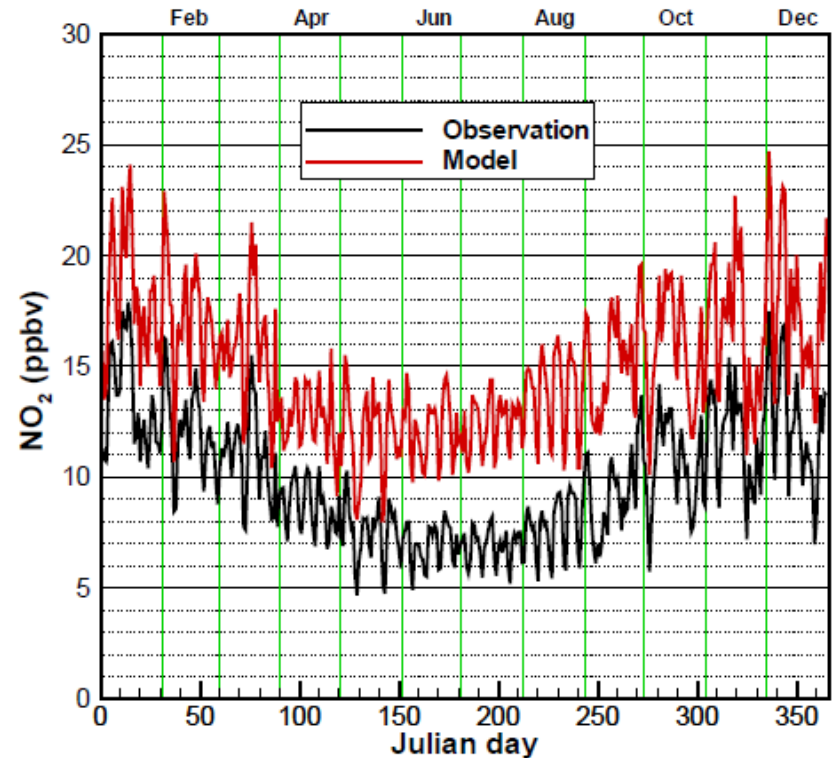
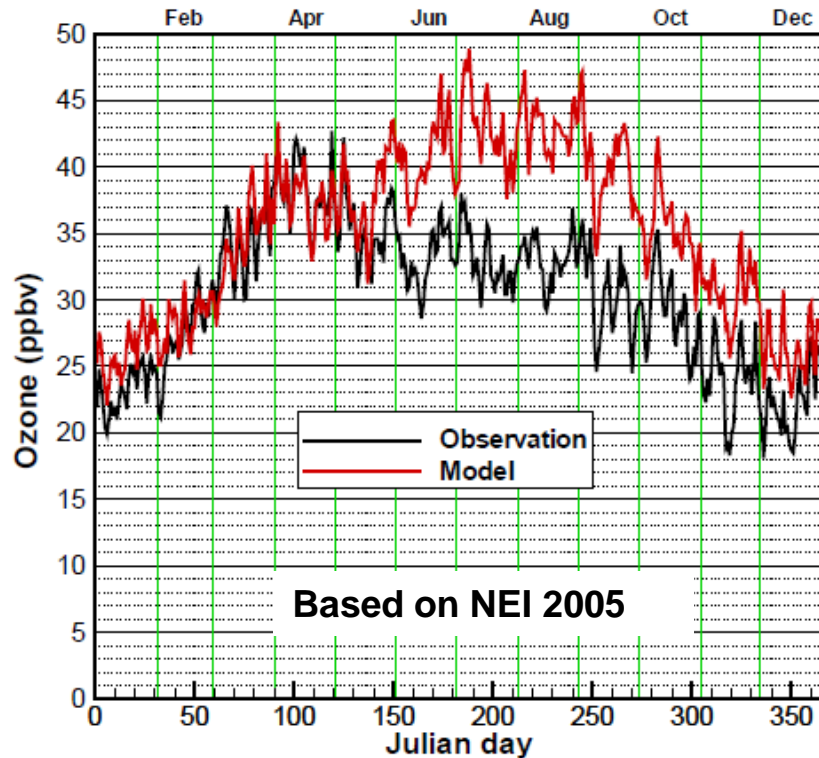
Maintaining prediction accuracy as the warning threshold was lowered and emissions of pollutants are changing

# Performance of operational ozone predictions

Fraction correct for 8h daily maximum of NOAA's operational ozone predictions for CONUS with respect to two thresholds

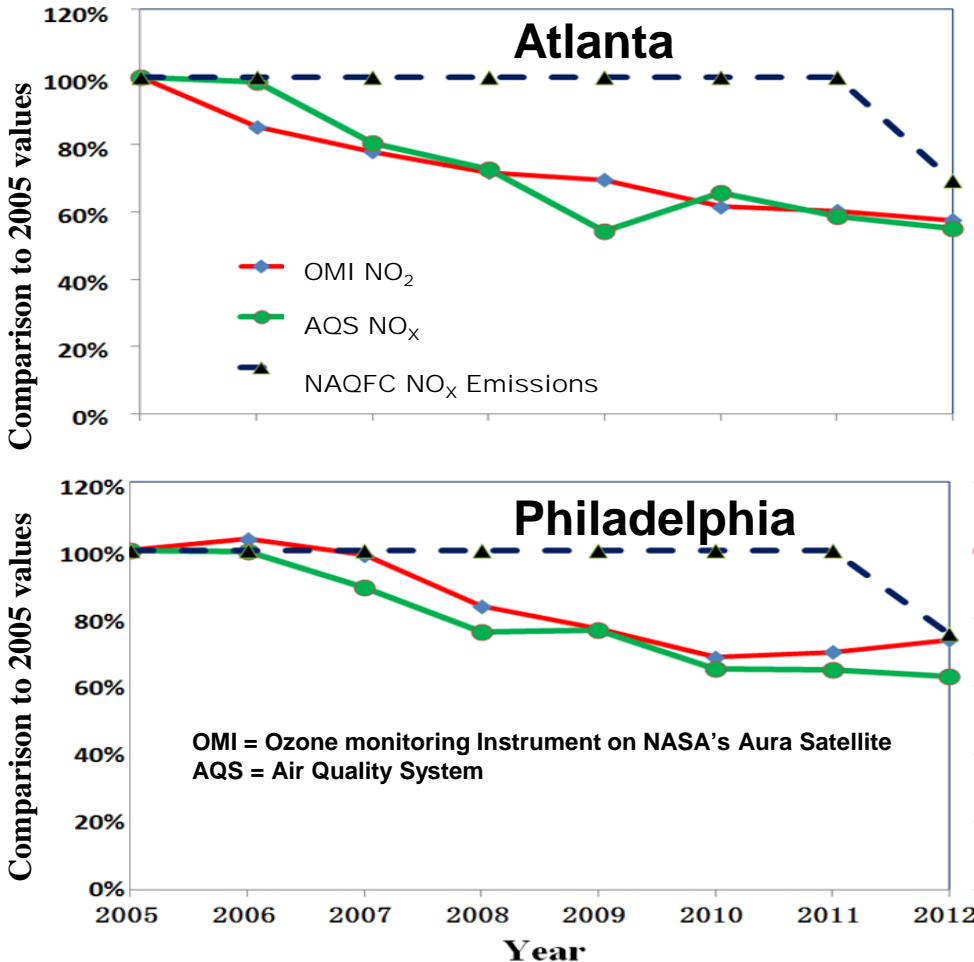


# Evaluation of experimental CB05 NAQFC ozone predictions for 2010, prior to emissions update



- *T. Chai et al., Geosci. Model Dev., 2013* (<http://www.geosci-model-dev.net/6/1831/2013/gmd-6-1831-2013.html>)
- Ozone overestimation in August is larger in rural areas, during morning hours, and in the southeast US
- NO<sub>2</sub> overestimation in August is larger at night time
- Ozone biases higher on weekends, but NO<sub>2</sub> biases higher on weekdays

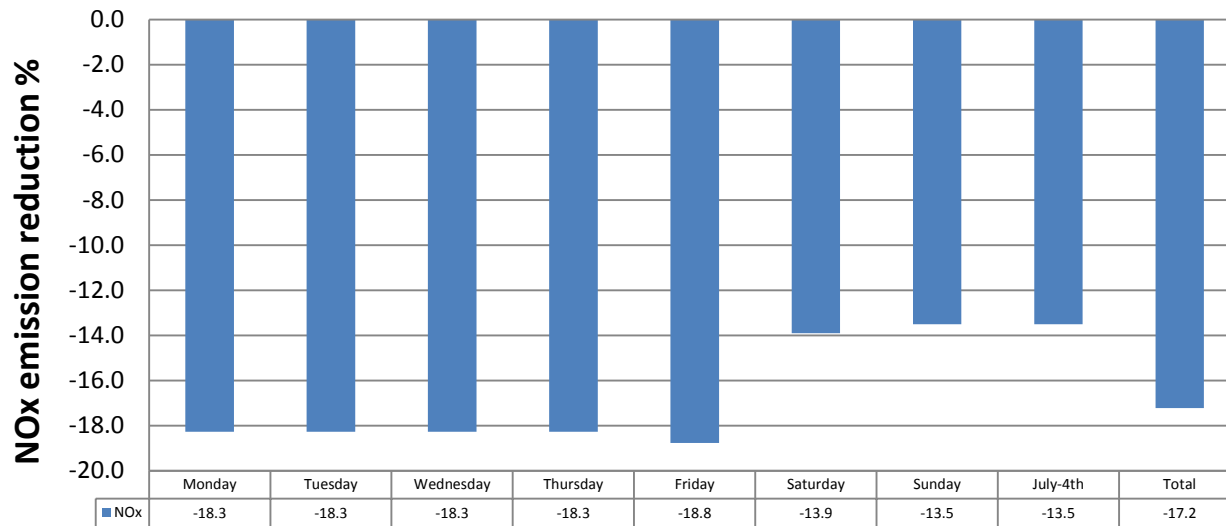
# NOx changes



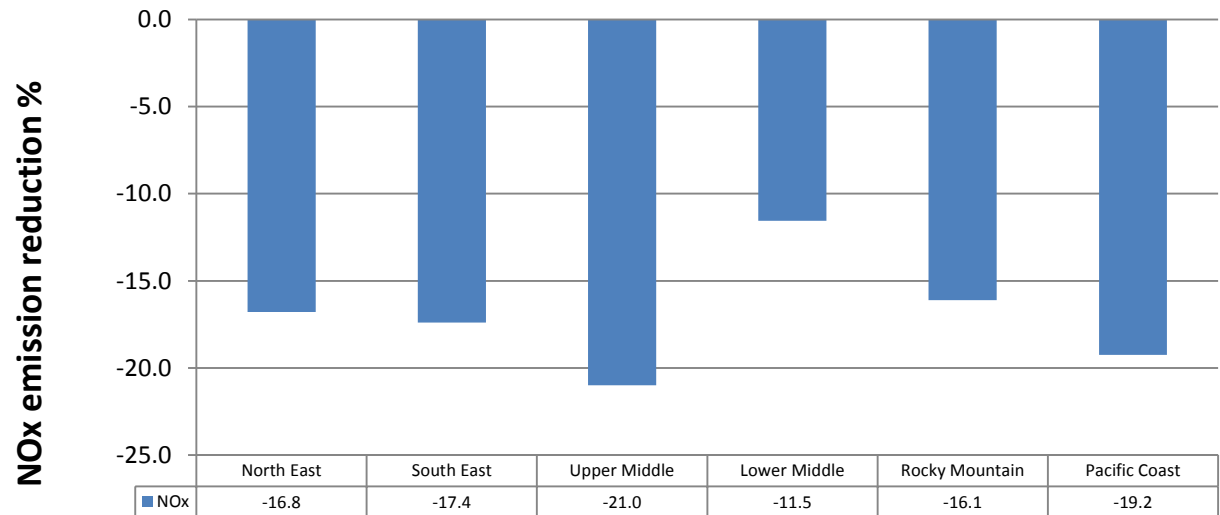
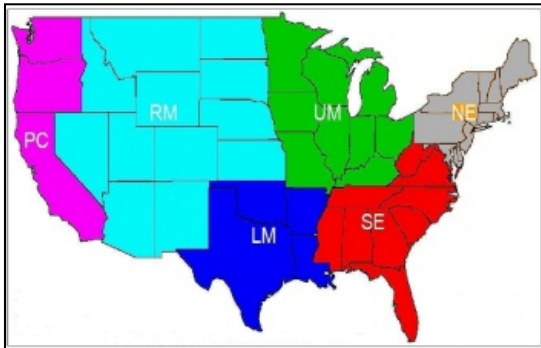
- Difference between NOx emissions used in 2012 and 2011 (blue indicates decrease in 2012).
- Mobile and nonroad emissions were updated based on projections for 2012.

Comparison of projected emissions with surface and satellite observations shows that projected reductions from 2005 to 2012 are similar to observed (*Tong et. al. Long-term NOx trends over large cities in US, Atm. Env. 2015*).

# Reduction in NO<sub>x</sub> emissions implemented in 2012



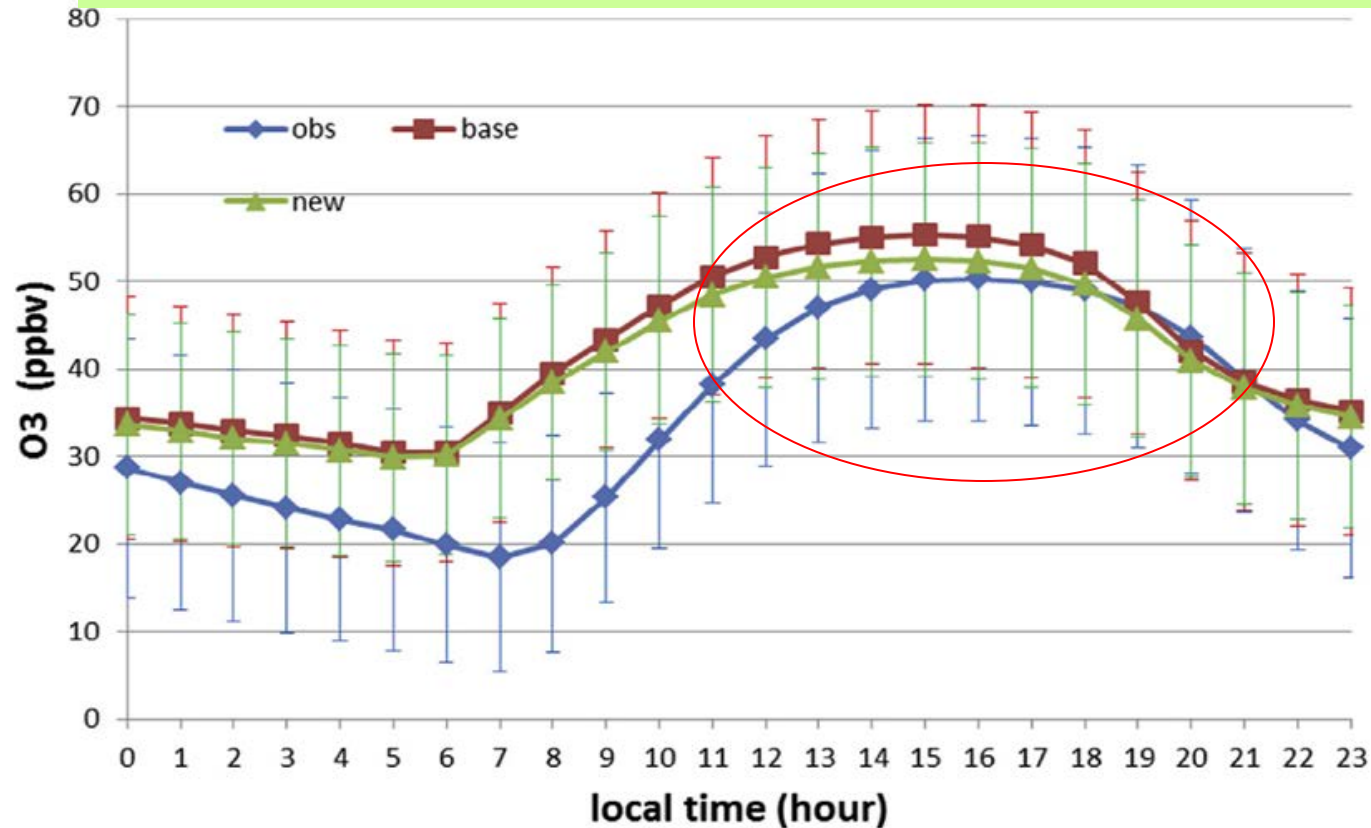
NO<sub>x</sub> emission reduction by region for July compared to those used in 2011





# Impact of NOx emissions update on ozone predictions

NOx emission used in July 2012 are 17.2% lower than those used in July 2011



Peak Ozone bias in summertime is reduced with updated emissions

(Pan et. al., Assessment of NOx and Ozone forecasting performance in the US NAQFC before and after the 2012 major emissions updates, Atmospheric Environment, 2014).



# NO<sub>x</sub> and Ozone biases over CONUS (in July 2011)

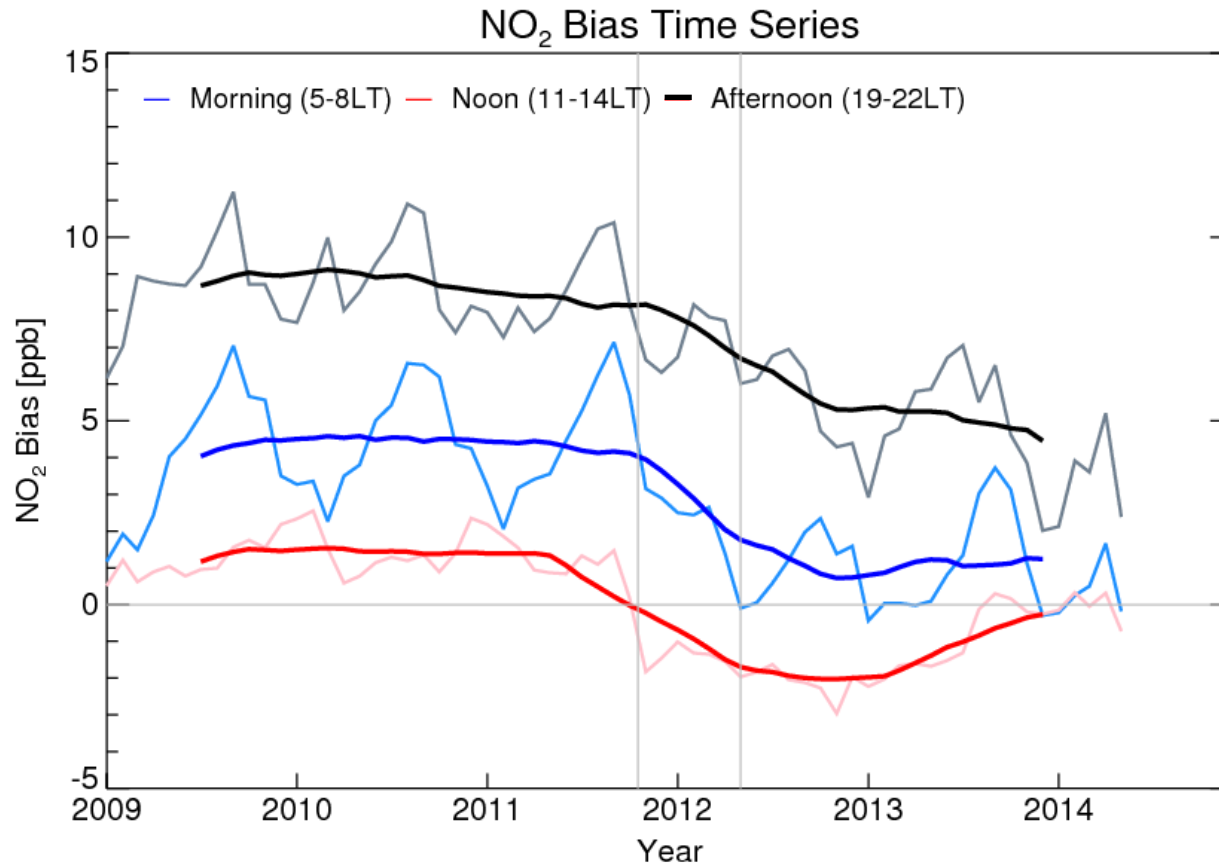
Land use	NO <sub>x</sub> _Bias <sup>a</sup> (ppbv)		ΔNO <sub>x</sub> (New- base)	O3_Bias <sup>b</sup> (ppbv)		ΔO3 (New- base)
	Base	New		Base	New	
Urban	2.8	0.46	-2.34	7.08	6.16	-0.92
Suburban	4.62	2.53	-2.09	7.48	6.22	-1.26
Rural	0.75	0.18	-0.57	7.8	5.93	-1.87

a The total number of NO<sub>x</sub> AQS sites is 295 including urban (101), suburban (111) and rural (83).

b The total number of ozone AQS sites is 1144 including urban (201), suburban (438) and rural (505).

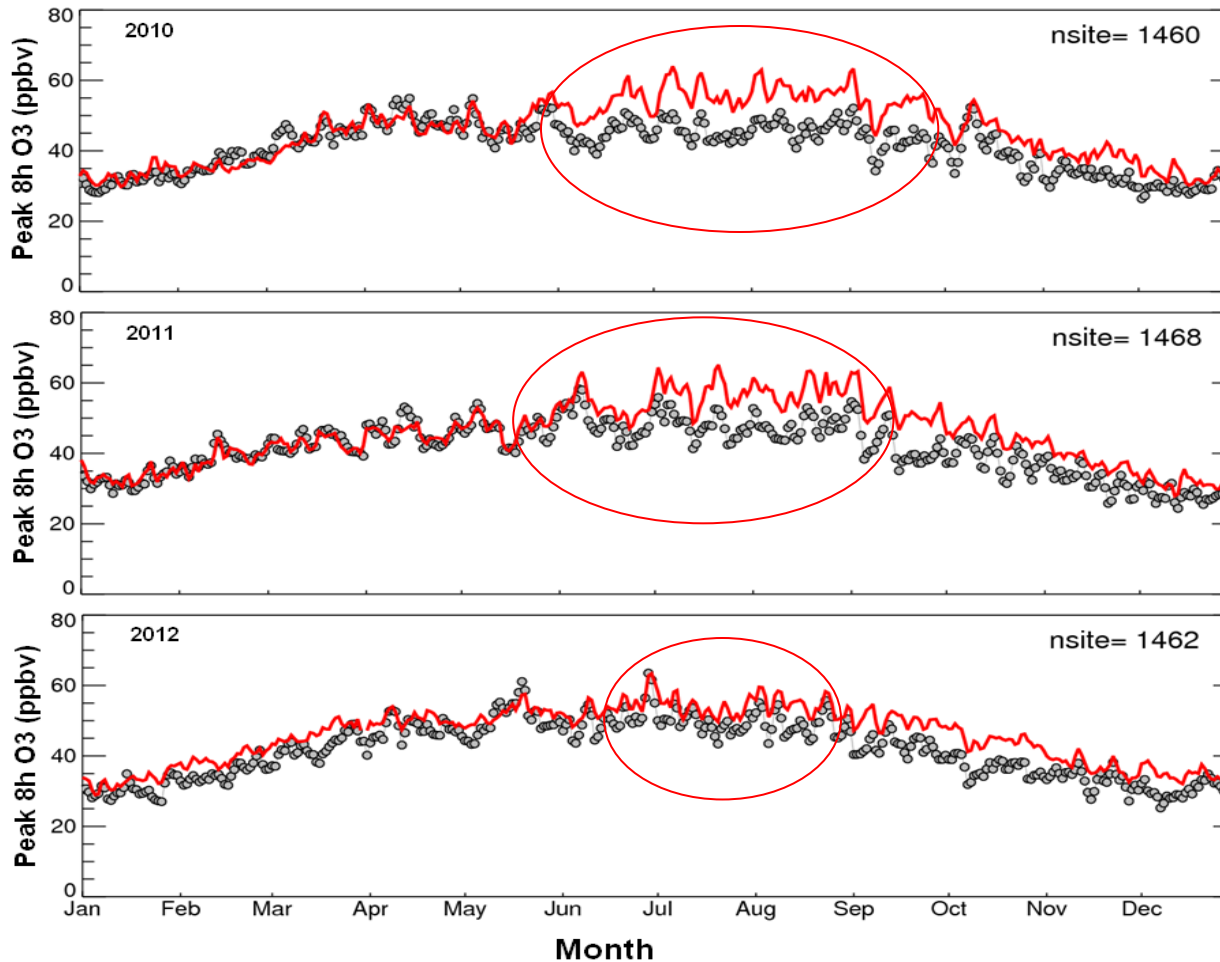
- **Positive biases reduced for all urbanization types for NO<sub>x</sub> and ozone.**
- **Largest improvements for NO<sub>x</sub> are in urban areas.**
- **Largest improvements for ozone in rural areas.**

# Impacts of model and emission updates on other species



NO<sub>2</sub> bias by time of the day was reduced following experimental model update in 2011 and emission update in 2012 (*Courtesy: Hyun-Cheol Kim*)

# Impact of emission update on ozone



Comparison of mean values over the continental US of daily maximum 8-hr Ozone concentrations from surface monitor observations (circles) and collocated NAQFC predictions (red line) for years 2010, 2011 and 2012.

# Smoke predictions

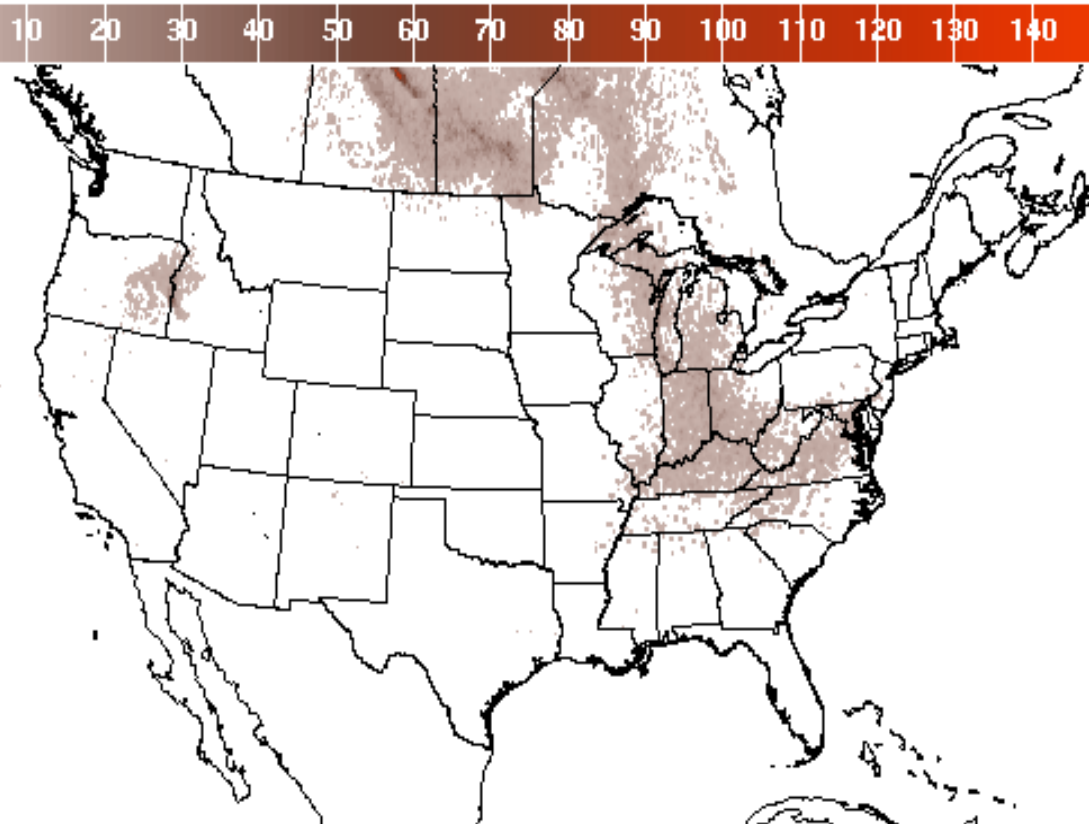
- Smoke predictions for CONUS (continental US), Alaska and Hawaii
- NESDIS provides wildfire locations
- Bluesky provides emissions estimates
- HYSPLIT model for transport, dispersion and deposition (Rolph et. al., W&F, 2009)
- Increased plume rise, decreased wet deposition, changes in daily emissions cycling
- Developed satellite product for verification (Kondragunta and Zeng)

Recent updates includes

- Automated detection of fires in Canada, Mexico and Central America
- 3-D particle model approach (rather than horizontal puffs) to properly represent the additional fires identified with automatic fire detection

Current testing includes

- Updated BlueSky System for smoke emissions

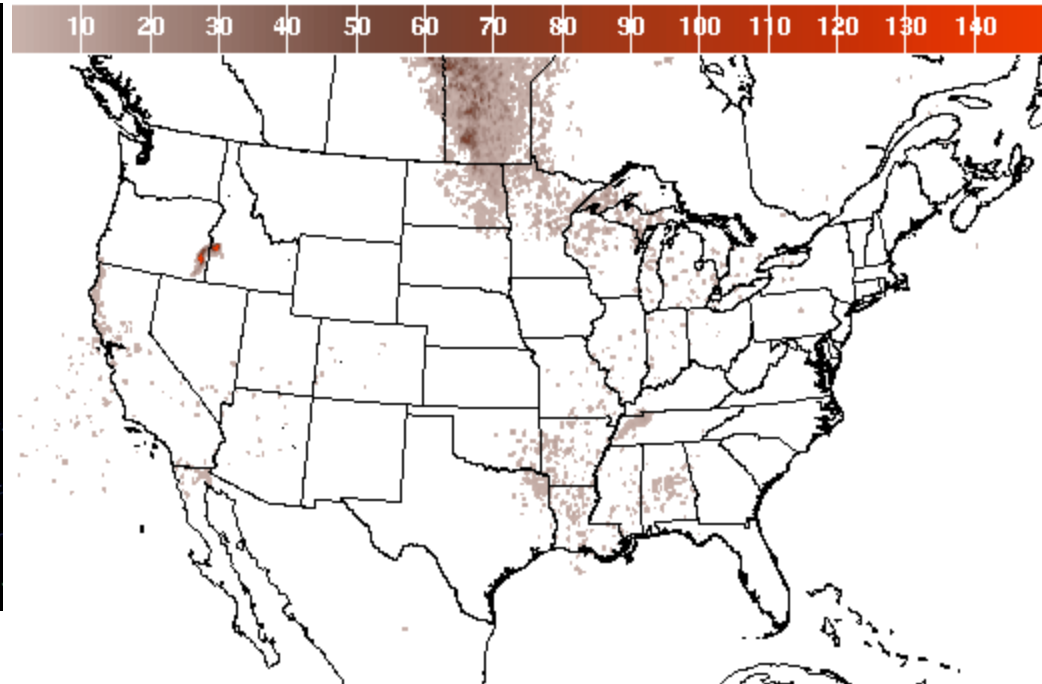
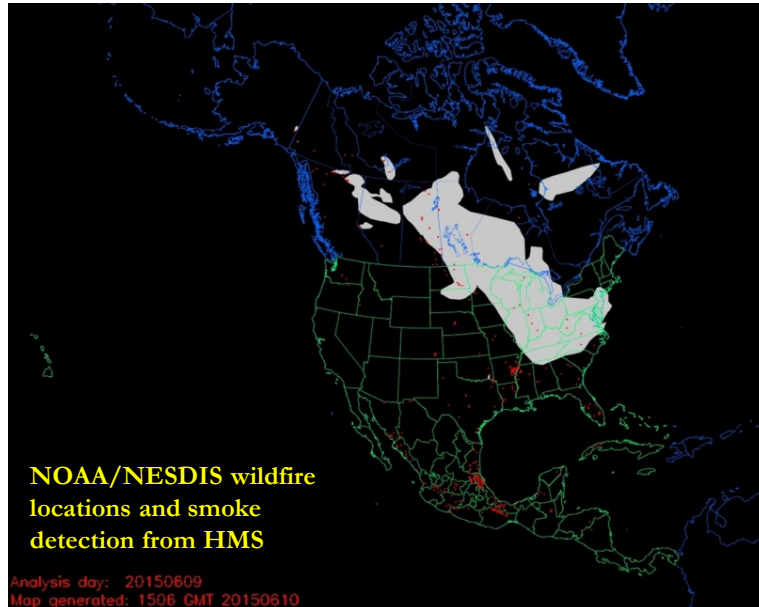


1Hr Surface Smoke (micrograms/m<sup>3</sup>) Tue Jun 09 2015 6PM EDT  
(Tue Jun 09 2015 22Z)

**National Digital Guidance Database**

06z model run Graphic created-Jun 08 7:20AM EDT

# Canadian wildfire smoke 6/9/2015



1Hr Surface Smoke (micrograms/m<sup>3</sup>) Mon Jun 08 2015 8AM EDT  
(Mon Jun 08 2015 12Z)



**National Digital Guidance Database**

06z model run

Graphic created-Jun 08 7:20AM EDT

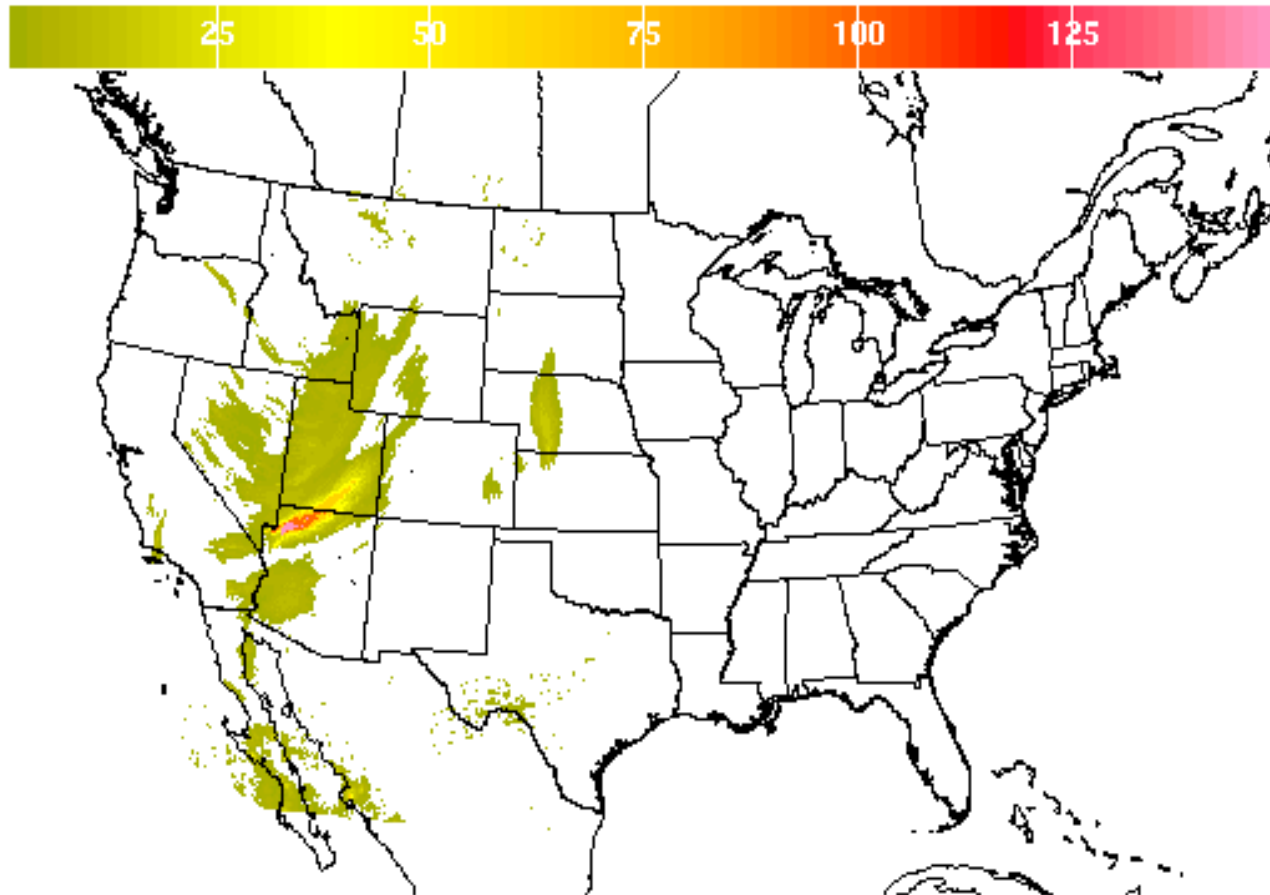
Fairfax, Virginia on June 9, 2015



Canadian wildfire smoke intrusion into CONUS was captured well by NOAA's operational smoke predictions

# CONUS dust predictions

Operational Predictions at <http://airquality.weather.gov/>



1Hr Vertical Dust (micrograms/m<sup>3</sup>) Tue Apr 14 2015 7PM EDT  
(Tue Apr 14 2015 23Z)

**National Digital Guidance Database**

12z model run

Graphic created-Apr 14 12:24PM EDT

Standalone prediction of airborne dust from dust storms:

- Wind-driven dust emitted where surface winds exceed thresholds over source regions
- Source regions with emission potential estimated from MODIS deep blue climatology for 2003-2006 (Ginoux et. al. 2010).
- Emissions modulated by real-time soil moisture.
- HYSPLIT model for transport, dispersion and deposition (Draxler et al., JGR, 2010)
- Wet deposition updates in July 2013
- Developed satellite product for verification (Ciren et.al., JGR 2014)



# Testing of PM<sub>2.5</sub> predictions

**AQ Forecaster Focus group access only. Test predictions produced by operational air quality system since January 2015**

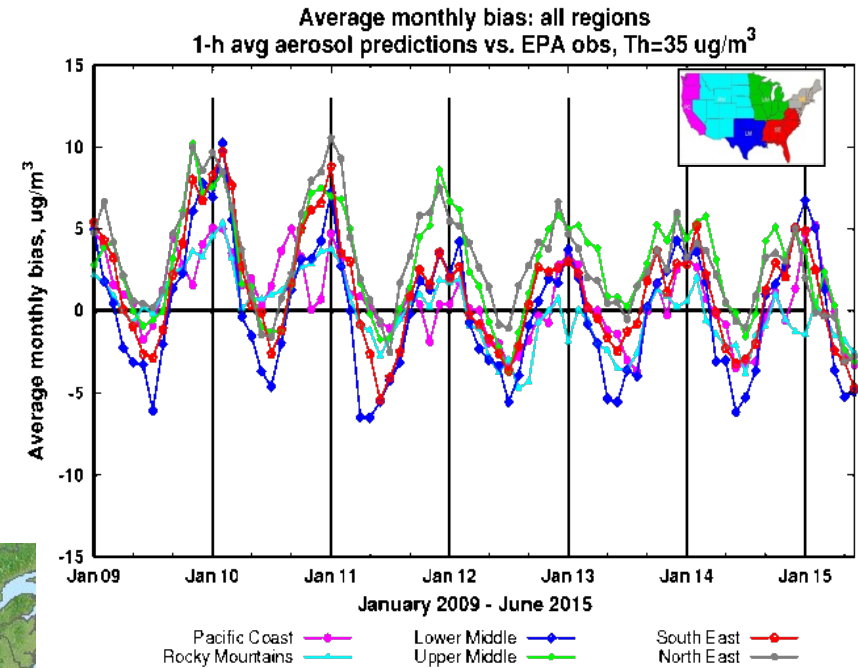
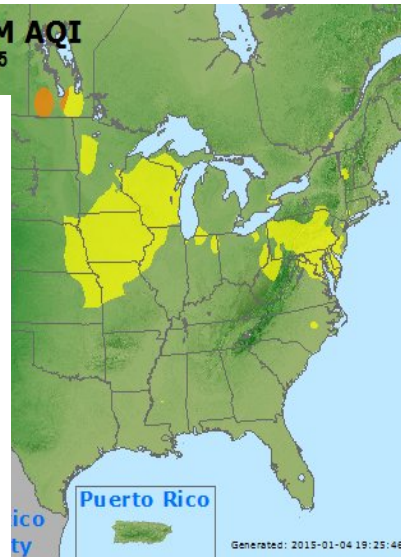
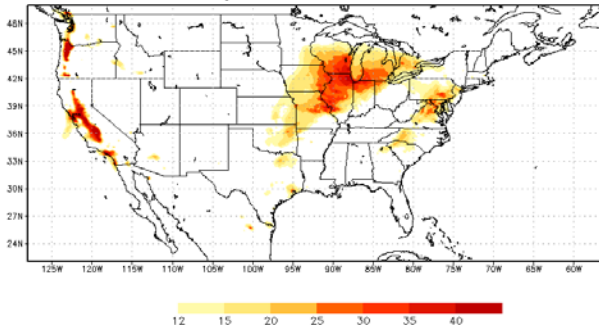
## Aerosols over CONUS

From NEI sources only before summer 2014

- CMAQ:  
CB05 gases, AERO-4 aerosols
- Sea salt emissions
- Seasonal prediction bias, testing bias correction post-processing algorithm

### Daily Average PM AQI Saturday, January 03, 2015

(Dev) 0-24h Averaging Surface PM<sub>2.5</sub> ( $\mu\text{g}/\text{m}^3$ )  
Starting at 12Z UTC, JAN-03-2015

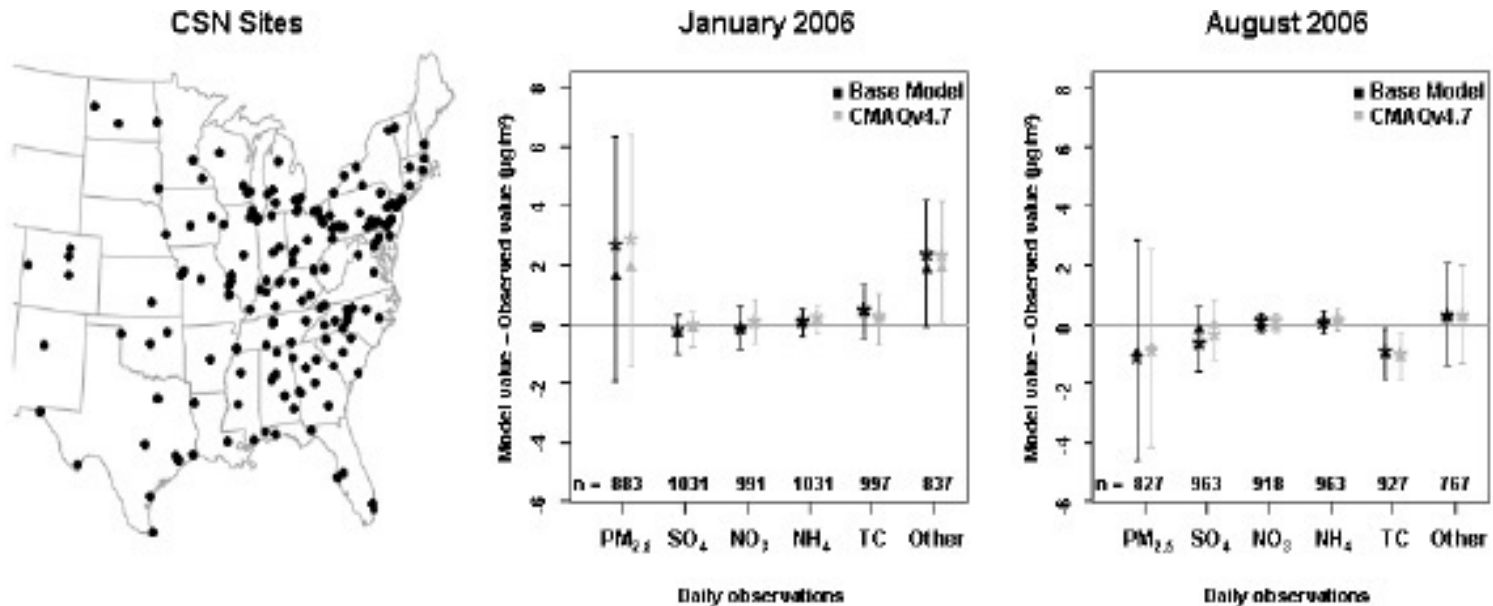


## Forecast challenges

- Improving sources for **wildfire smoke and dust** – in testing since summer 2014
- Chemical mechanisms eg. SOA
- Meteorology eg. PBL height
- Chemical boundary conditions/trans-boundary inputs



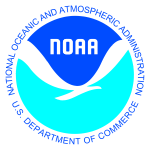
# Seasonal bias in PM<sub>2.5</sub> prediction



Mean (star), median (triangle), and inter-quartile ranges of model bias (model value – observed value) for multiple fine-particle species measured at CSN sites in the 12km domain. The number of model/observation pairs for each species is shown above the x-axis.

The bias in the total mass of PM<sub>2.5</sub> is dominated by overpredictions of unspecified PM in the winter and by underpredictions of carbon aerosols in the summer. (Foley et. al., *Incremental testing of the Community Multiscale Air Quality (CMAQ) modeling system version 4.7*, *Geosci. Model Dev.*, 3, 205-226, 2010)

Saylor et. al. found same type of seasonal speciation biases in the CMAQ v4.6 for IMPROVE sites.



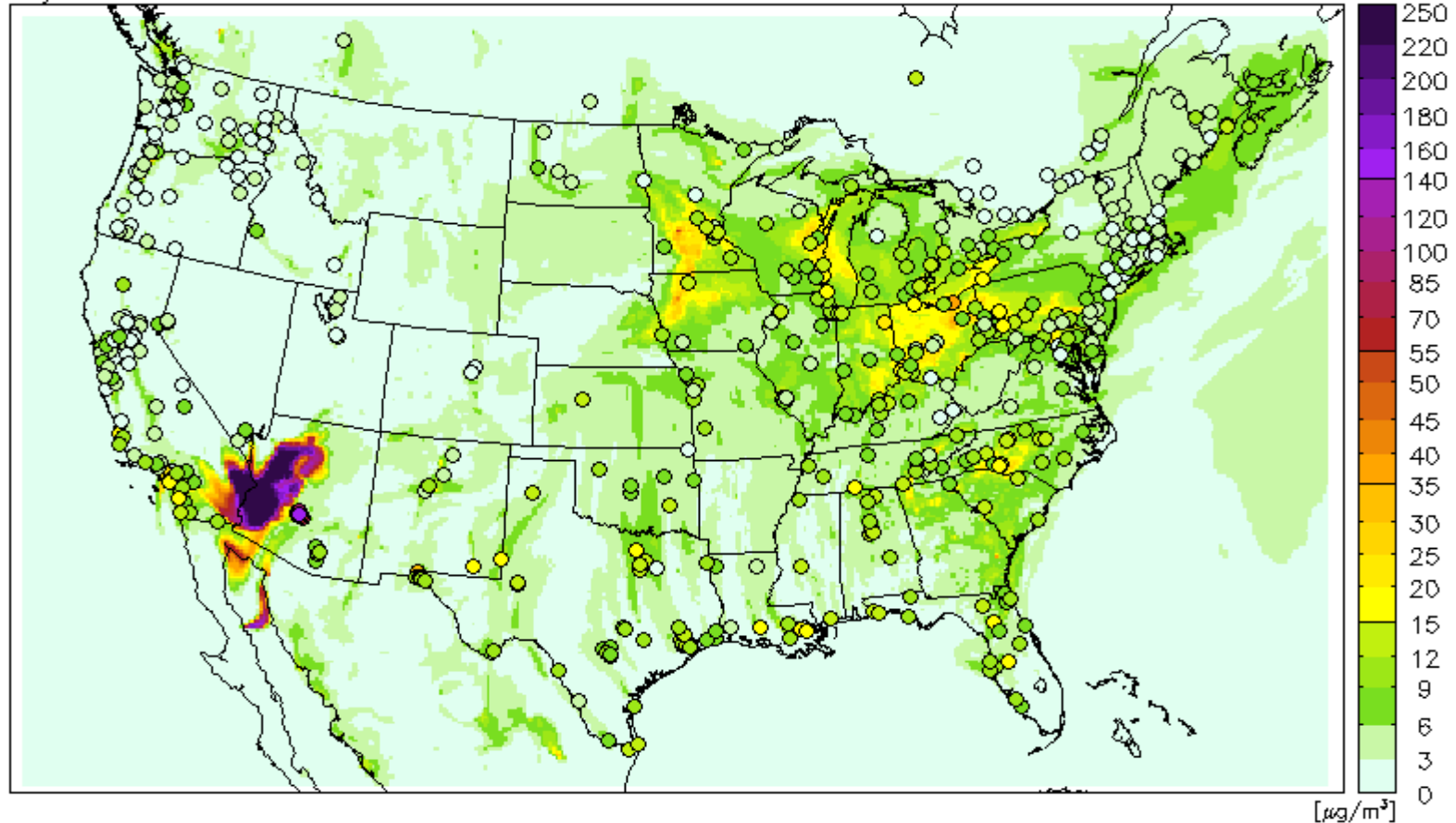
# Updates to CMAQ system for CONUS domain in January 2015

- Carbon Bond gas-phase Mechanisms (CB05) with updated rate constants and linkage with the particulate phase through heterogeneous reactions,
- Monthly varying lateral boundary conditions for 36 gaseous and aerosol species below 7 km altitude,
- Modified dry deposition velocity calculation,
- Planetary boundary layer height in the model constrained to be at least 50 m,
- Faster removal of organic nitrate from the atmosphere,
- Windblown dust emissions are included using threshold friction velocity and soil wetness fraction with climatological source composition and locations.
- Inclusion of particulate emissions from wild fires based on wildfire locations observed over the previous day,
- Suppression of soil emissions when terrain is covered by ice or snow,

Simplify maintenance of AQ predictions by unifying prediction code for CONUS, AK and HI.

# Blowing dust event in testing of PM<sub>2.5</sub> predictions

May 11 2014 12:00 UTC



Independent  
NOAA/NESDIS  
analysis narrative  
based on  
satellite imagery:

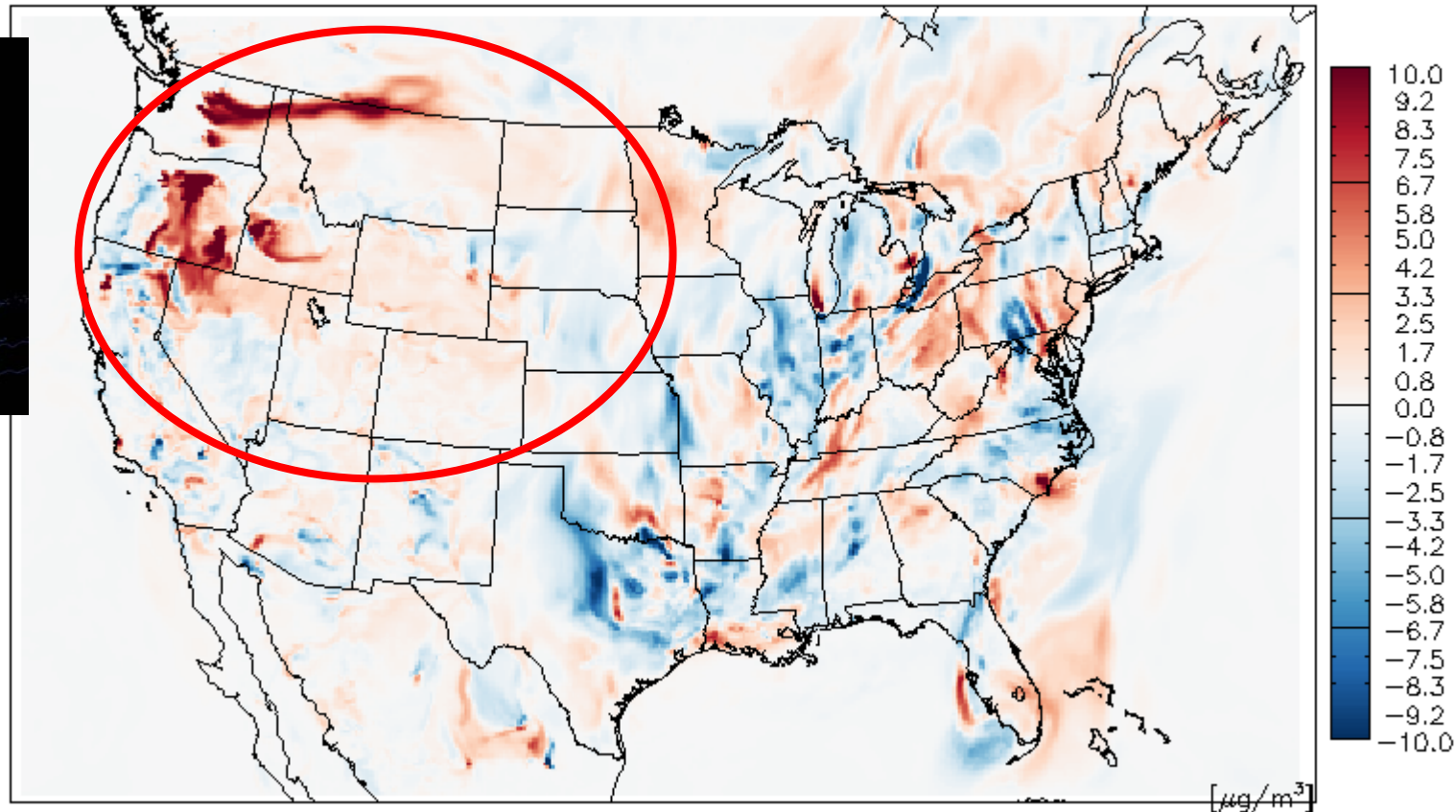
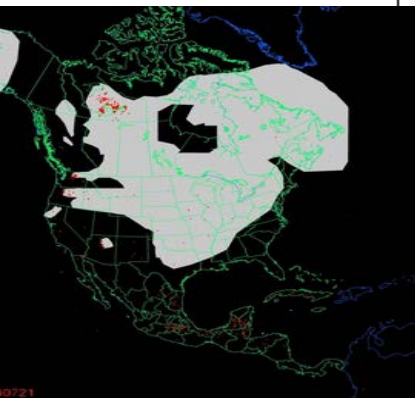
## BLOWING DUST

**California/Arizona:** An area of moderately dense blowing dust was visible sweeping across northern Baja California/Arizona into western New Mexico behind a strong cold frontal boundary. This remnant dust originated from multiple areas in southern California last evening.

# Impact of forest fires in testing of PM<sub>2.5</sub> predictions

Difference between two PM<sub>2.5</sub> predictions:  
with-minus-without fire emissions

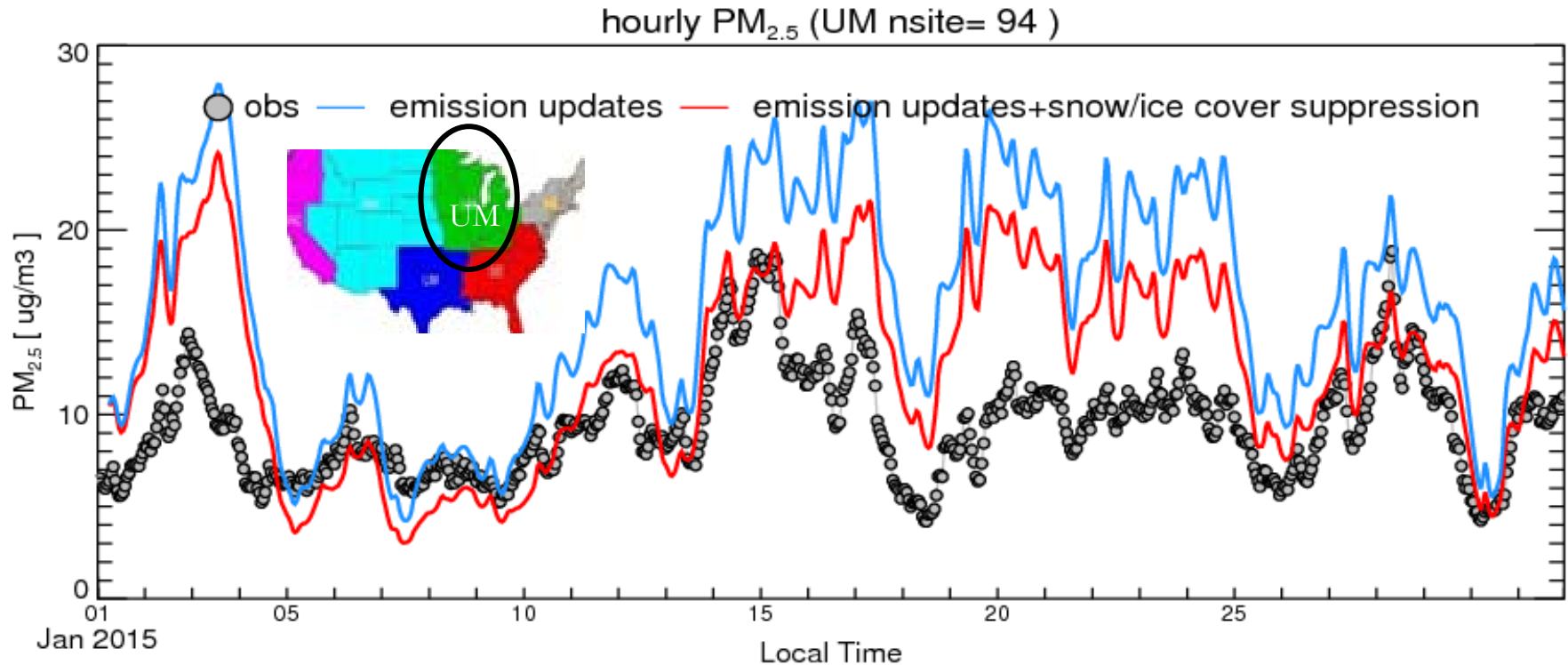
Jul 20 2014 13:00 UTC



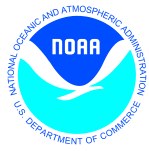
NOAA NESDIS  
Hazard Mapping  
System Fire and  
Smoke Analysis

Detection of  
wildfire locations  
from satellite  
imagery

# Snow/ice suppression of soil emissions



	Case		Mean (ug/m <sup>3</sup> )	Bias (ug/m <sup>3</sup> )	NME (%)	RMSE (ug/m <sup>3</sup> )	Corr. coef., r
UM	Jan 2015 (data-size=650)	observations	9.42				
		emission updates	15.93	6.51	69	11.7	0.48
		emission updates + snow/ice cover suppression	12.52	3.1	33	8.94	0.46



# Current testing of CMAQ updates and near-term plans

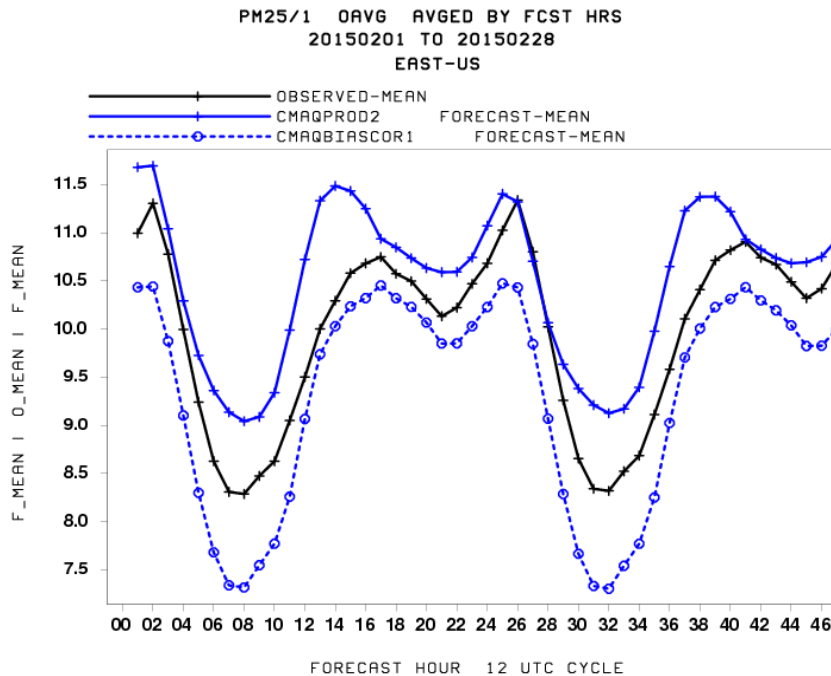


- Partial update of emissions using NEI 2011 (since May 2015)
- Including lateral boundary conditions from global dust predictions
- Increased vertical resolution from 22 to 35 layers
- Testing analog forecast technique for PM<sub>2.5</sub> bias correction (*Djalalova I, Delle Monache L, Wilczak: PM<sub>2.5</sub> analog forecast and Kalman filter post-processing for the Community Multiscale Air Quality (CMAQ) model, Atmospheric Environment, 2015*)
- Update to a newer version of BlueSky smoke emission system

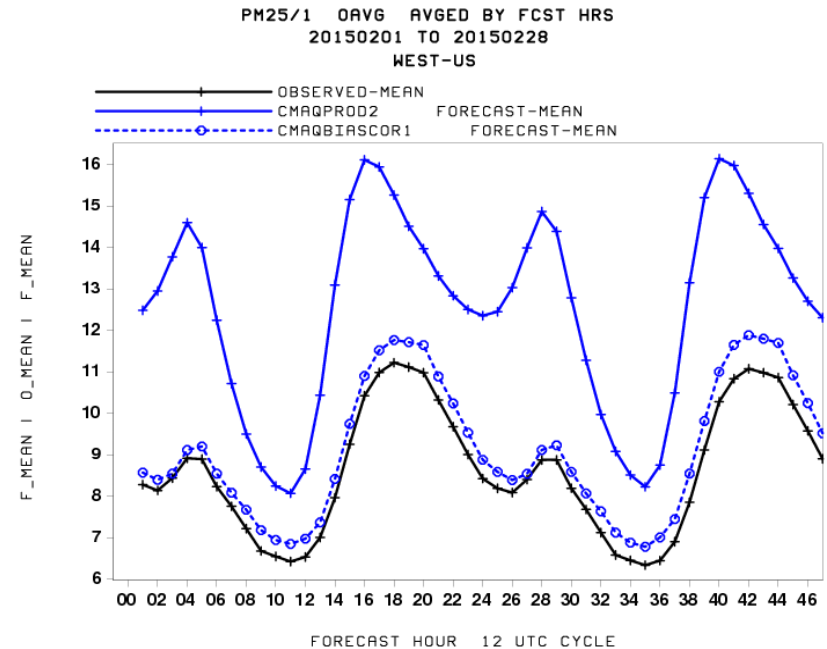


# Bias Correction for developmental PM2.5 predictions

## Eastern US



## Western US





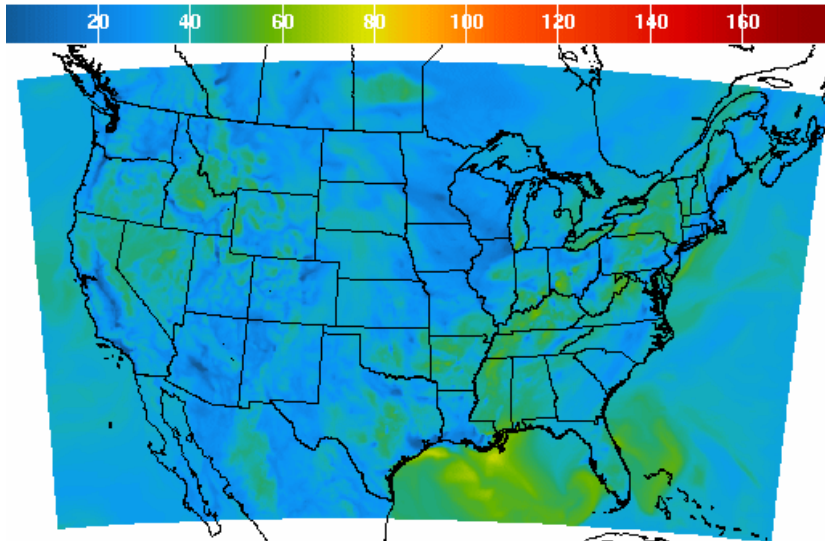
# Summary and plans

## US national AQ forecasting capability:

- Operational **ozone** prediction nationwide; CMAQ with CB05 mechanism
- Operational **smoke** prediction nationwide
- Operational **dust** prediction from CONUS sources
- Prototype CMAQ **PM2.5** predictions with NEI, wildfire and dust emissions:
  - Bias correction and linkages with global dust predictions in testing
  - Evaluation for potential experimental (public) release.

# Operational AQ forecast guidance

## [airquality.weather.gov](http://airquality.weather.gov)



1Hr Avg Ozone Concentration(PPB) Ending Thu Sep 20 2007 10AM EDT  
(Thu Sep 20 2007 14Z)

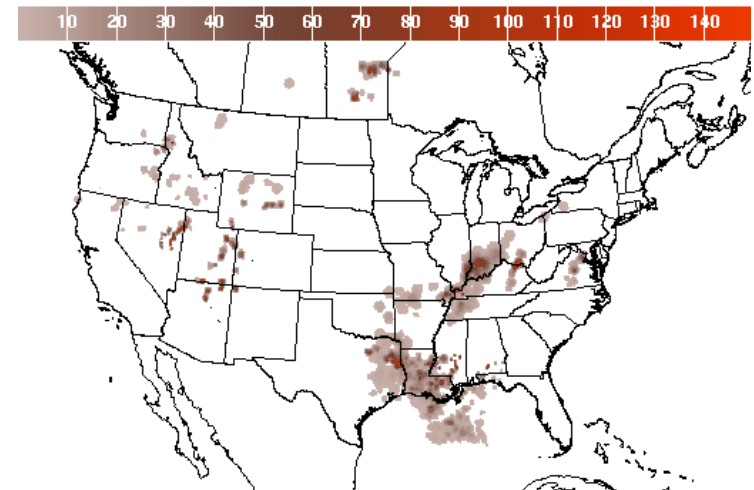


National Digital Guidance Database  
06z model run Graphic created-Sep 20 7:23AM EDT



**Smoke Products**  
**Nationwide since 2010**  
**Dust Products**  
**Implemented 2012**

**Ozone products**  
**Nationwide since 2010**

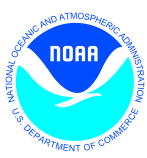


1Hr Surface Smoke (micrograms/m<sup>3</sup>) Thu Sep 20 2007 9AM EDT  
(Thu Sep 20 2007 13Z)



National Digital Guidance Database  
6z model run Graphic created-Sep 20 8:24AM EDT

Further information: [www.nws.noaa.gov/ost/air\\_quality](http://www.nws.noaa.gov/ost/air_quality)



# Acknowledgments:

## *AQF implementation team members*



*Special thanks to previous NOAA and EPA team members who contributed to the system development*

**NOAA/NWS/OSTI**

*Ivanka Stajner*

*NAQFC Manager*

**NWS/AFSO**

*Jannie Ferrell*

*Outreach, Feedback*

**NWS/OD**

*Cynthia Jones*

*Data Communications*

**NWS/OSTI/MDL**

*Jerry Gorline, Marc Saccucci,*

*Dev. Verification, NDGD Product Development*

*Dave Ruth*

**NWS/OSTI**

*Sikchya Upadhayay*

*Program Support*

**NESDIS/NCDC**

*Alan Hall*

*Product Archiving*

**NWS/NCEP**

*Jeff McQueen, Jianping Huang, Ho-Chun Huang*

*AQF model interface development, testing, & integration*

*Jun Wang, \*Sarah Lu*

*Global dust aerosol and feedback testing*

*\*Brad Ferrier, \*Eric Rogers,*

*NAM coordination*

*\*Hui-Ya Chuang*

*Geoff Manikin*

*Smoke and dust product testing and integration*

*Rebecca Cosgrove, Chris Magee*

*NCO transition and systems testing*

*Mike Bodner, Andrew Orrison*

*HPC coordination and AQF webdrawer*

**NOAA/OAR/ARL**

*Pius Lee, Daniel Tong, Tianfeng Chai*

*CMAQ development, adaptation of AQ simulations for AQF*

*Li Pan, Hyun-Cheol Kim, Youhua Tang*

*Ariel Stein*

*HYSPLIT adaptations*

**NESDIS/STAR** *Shobha Kondragunta*

*Smoke and dust verification product development*

**NESDIS/OSDPD** *Liqun Ma, Mark Ruminski*

*Production of smoke and dust verification products,*

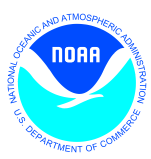
*HMS product integration with smoke forecast tool*

**EPA/OAQPS** *partners:*

*Chet Wayland, Phil Dickerson, Brad Johns, John White*

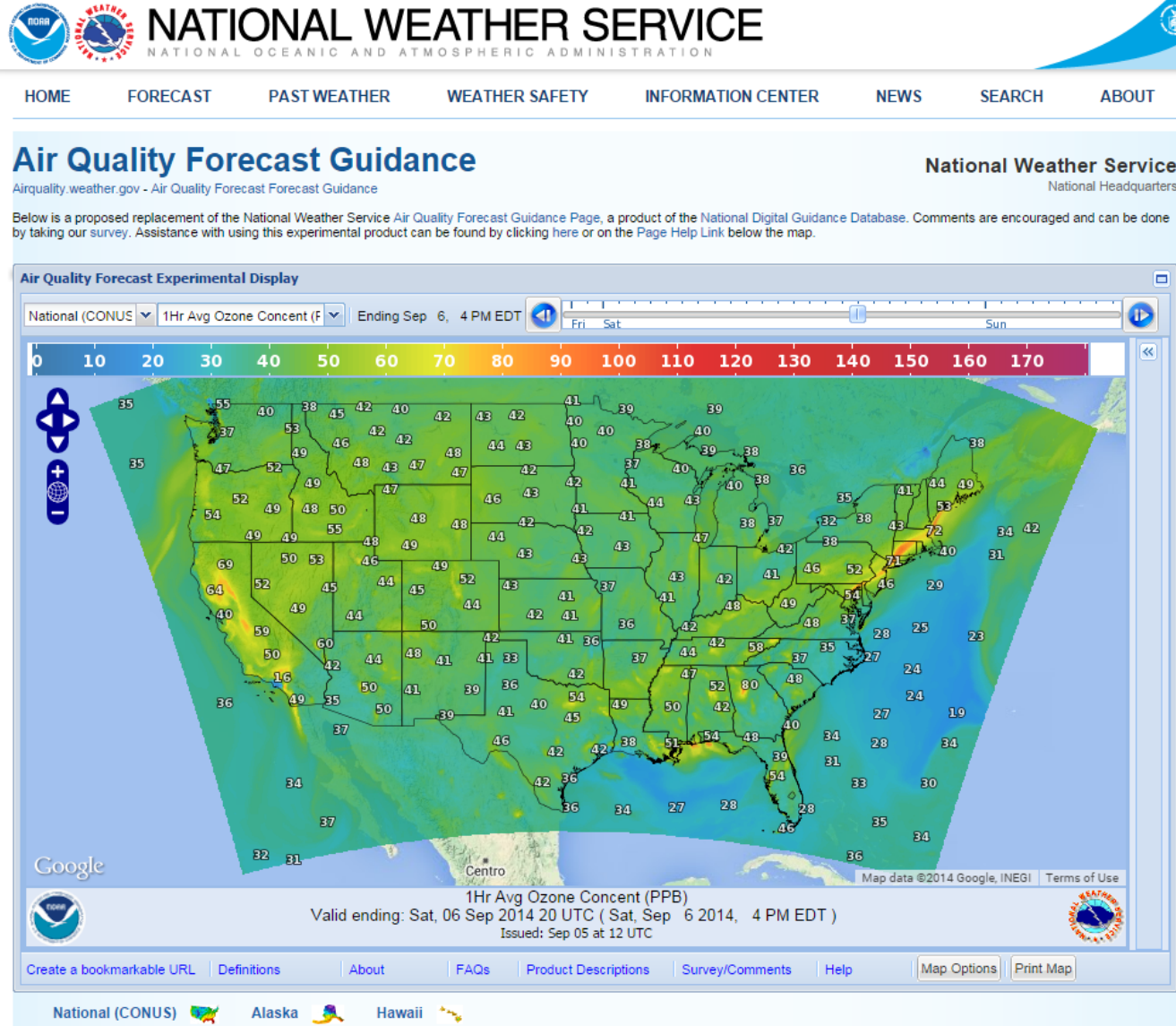
*AIRNow development, coordination with NAQFC*

\* Guest Contributors

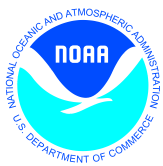


# Backup

# Testing new display of AQ predictions



<http://preview.weather.gov/graphical/?dataset=aq>



# Summary of Emission Data Sources for 2014

## ❖ Area Sources

- US EPA Projected 2012 Nonroad + 2005 NEIs for other sectors;
- Canada 2006 Emission Inventory;
- Mexico 1996 EI for six border states;

## ❖ Mobile Sources (onroad)

- 2005 NEI with Cross-State Air Pollution Rule (CSAPR) projection for US sources
- Canada 2006 Emission Inventory;

## ❖ Point Sources (EGUs and non-EGUs)

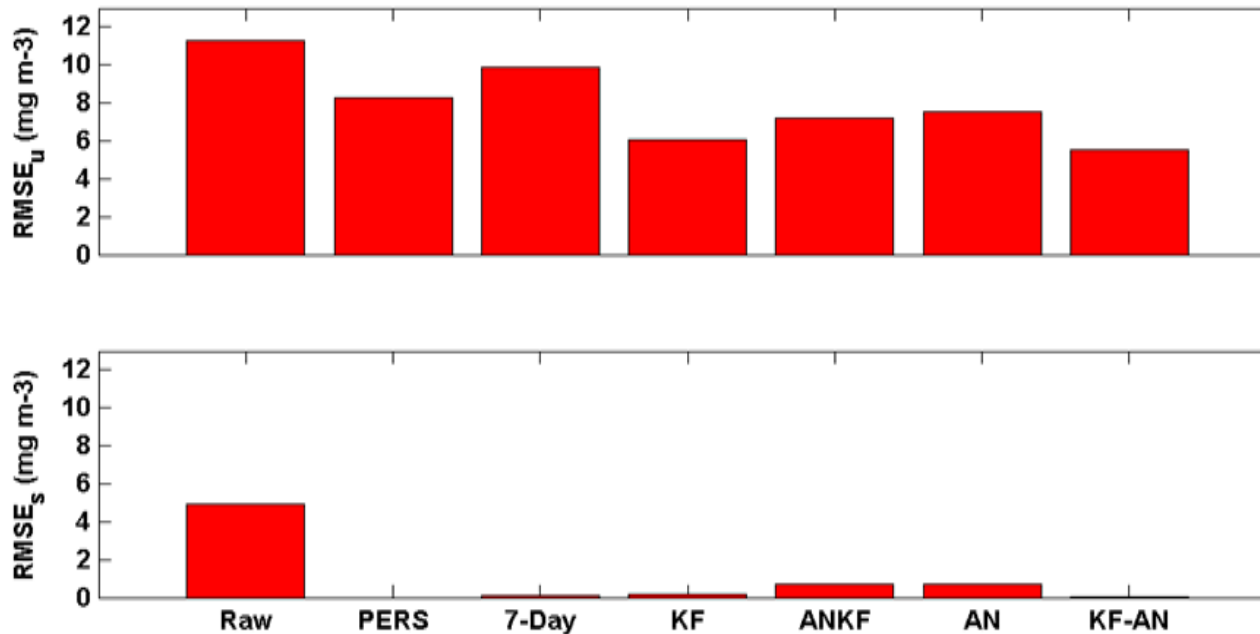
- NEI 2005 for base year;
- Updated with 2012 Continuous Emission Monitoring (CEM) data for EGUs;
- Projected into forecast year using DOE Annual Energy Outlook (2014) factors;

## ❖ Natural Sources

- *Terrestrial biogenic emission:* BEIS model v3.14
- *Sea-salt emission:* CMAQ online Sea-salt emission model;

# Removal of Bias in PM<sub>2.5</sub> predictions

- Quality control of the observations is essential
- Five different post-processing techniques were tested



Raw: Hourly AIRNow data available in real-time

PERS: Persistence forecast

7-day: 7-day running mean subtraction

KF: Kalman-filter approach

ANKF: Analog forecast technique followed by Kalman filter approach

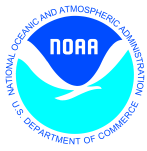
AN: Analog Forecast technique

KF-AN: Kalman-filter approach followed by Analog forecast technique

Unsystematic component of the RMSE (top panel) and systematic component of RMSE (bottom panel) using hourly values for the month of November evaluated at the 518 AIRNow PM<sub>2.5</sub> sites.

*Djalalova I, Delle Monache L, Wilczak: PM<sub>2.5</sub> analog forecast and Kalman filter post-processing for the Community Multiscale Air Quality (CMAQ) model, Atmospheric Environment, 2015.*





# Partnering with AQ Forecasters



## ***Focus group, State/local AQ forecasters:***

- Participate in real-time developmental testing of new capabilities, e.g. aerosol predictions
- Provide feedback on reliability, utility of test products
- Local episodes/case studies emphasis
- Regular meetings; working together with EPA's AIRNow and NOAA
- ***Feedback is essential for refining/improving coordination***

## ***Examples of AQ forecaster feedback after emissions update in 2012:***

- In Maryland, NOAA ozone predictions have improved since 2011: significant improvement in false alarm ratio (FAR) with some decrease in probability of detection (POD). (*Laura Landry, Maryland Department of the Environment*)

## ***Updates in 2014:***

- In Connecticut, *The late summer over-prediction has been nearly eliminated. The CB05/AERO-4 model looks good for production.* (*Michael Geigert, Connecticut Department of Energy and Environmental Protection*)

Currently evaluating updates in ozone, smoke and dust predictions and updates in testing of PM2.5 predictions